Development of an Advanced Urban Dispersion Modeling Capability

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Accurate and timely prediction of atmospheric dispersion of hazardous materials is a critical national security need.

- **High-fidelity urban dispersion simulations are important:**

  - Experimental measurements alone are insufficient for emergency response and planning

  - Field experiments are expensive

  - Simulations are used to guide more effective sensor deployments

  - Together with measurements, simulations are an essential tool for event reconstruction
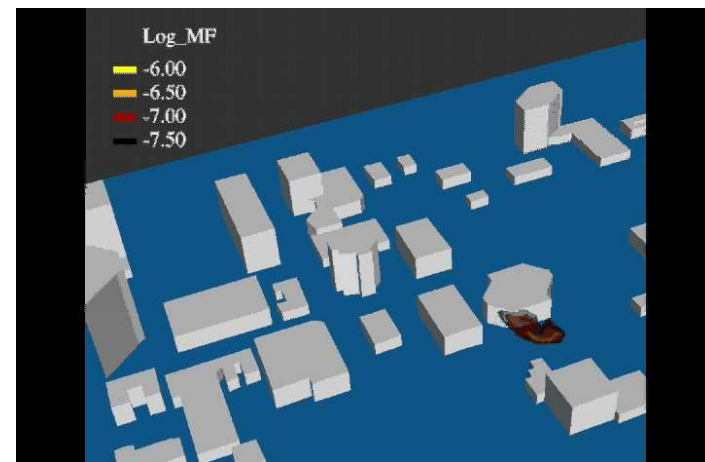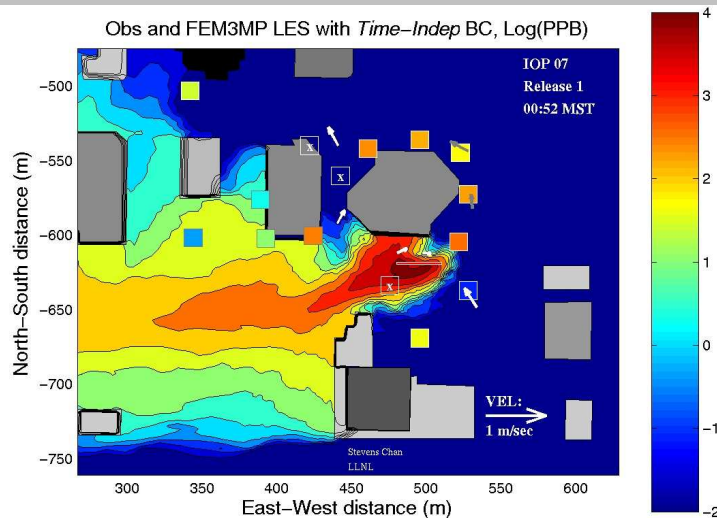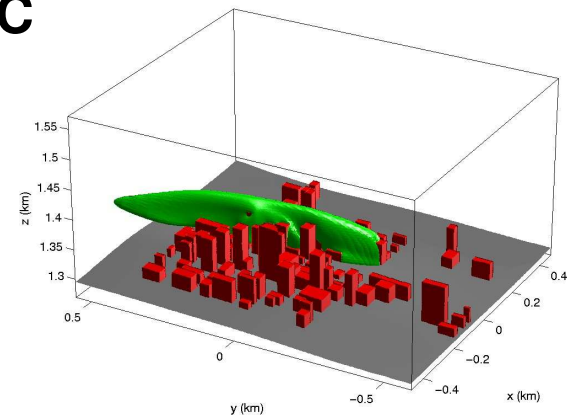
Urban dispersion modeling capabilities have been developed by researchers in NARAC

- **The standalone FEM3MP code is the primary urban dispersion modeling code used in the atmospheric sciences division in NARAC**

  — Finite element incompressible CFD

  — Structured mesh

  — LES & RANS turbulence models

  — Atmospheric chemistry

- **<u>Operational</u> use limited due to**

  — Simple geometry representation

  — Laborious grid generation

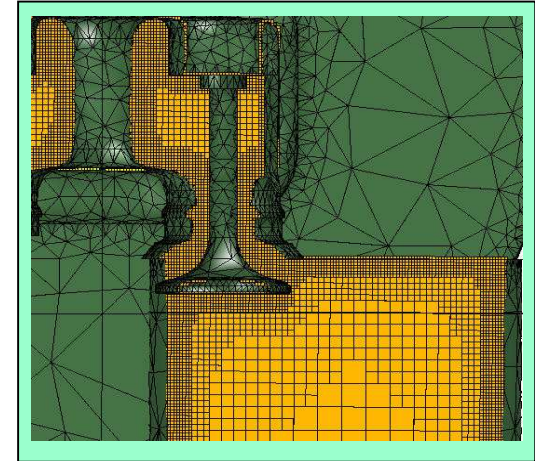 — Range of release scenarios (e.g. unable to simulate moving sources)
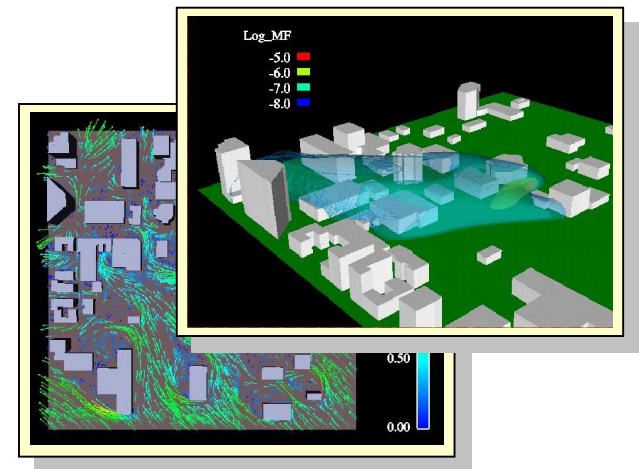
We propose to apply advanced meshing tools to the numerical models developed in NARAC
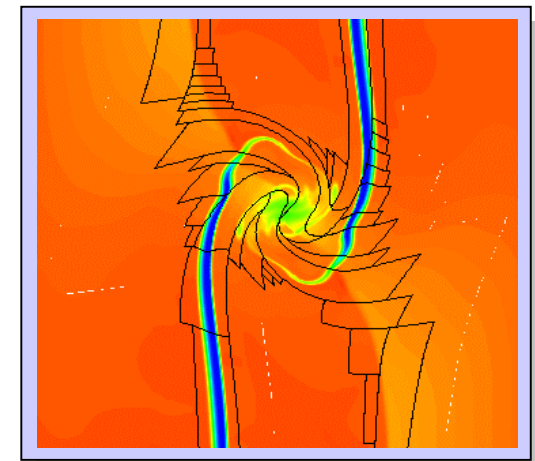
- **The Overture project has tools for rapid geometry-to-mesh (Rapsodi) capability**
  - Rapid construction of surface grids from CAD data
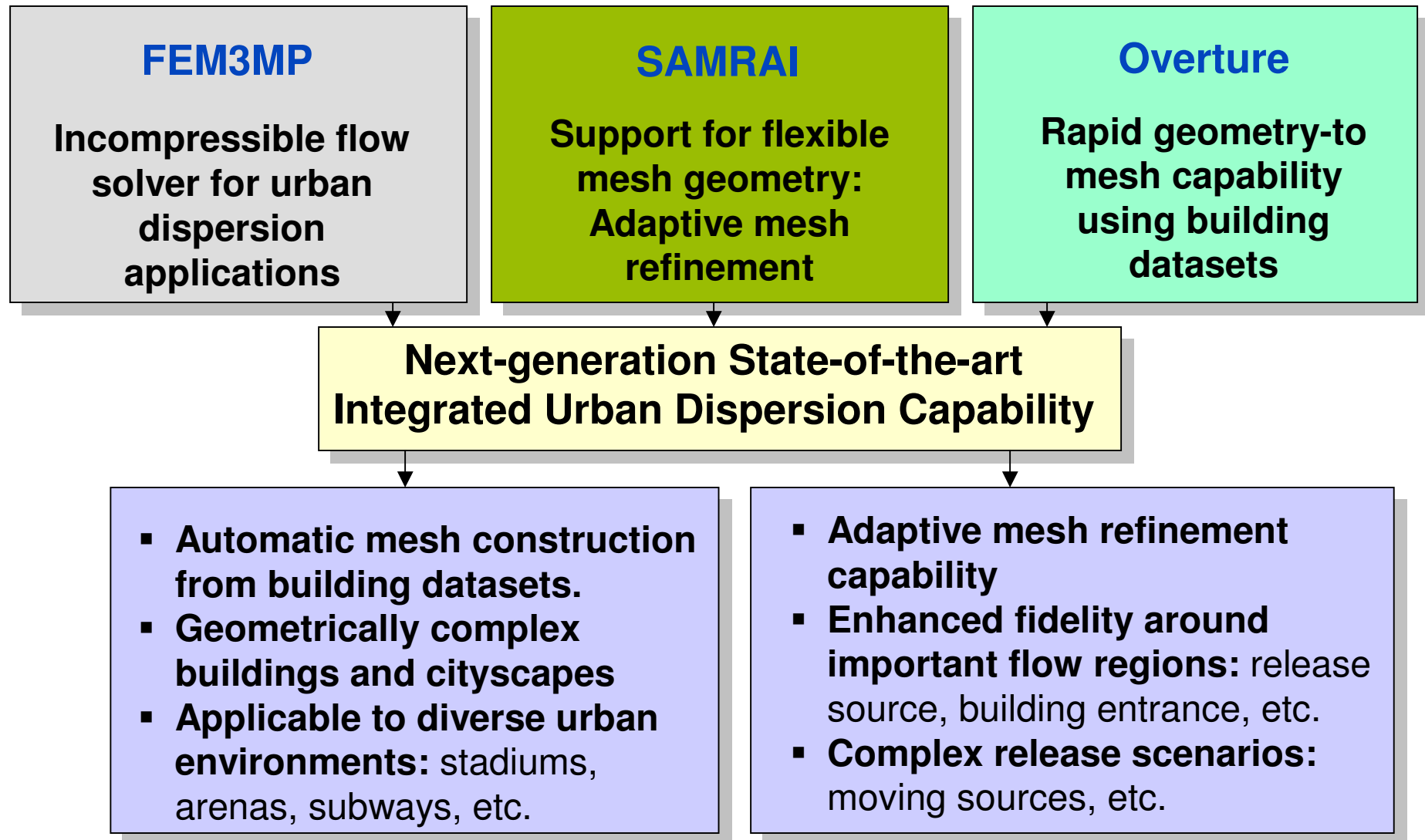 - Interfaces to fast volume grid generator from NASA (CUBES)

- **The SAMRAI infrastructure supports a variety of parallel AMR applications**
  - Data structures for flexible mesh geometry
  - Adaptive mesh refinement
  - Scalability verified on > 1K processors

The coupled technologies will lead to an advanced operational capability

FEM3MP

Incompressible flow solver for urban dispersion applications

SAMRAI

Support for flexible mesh geometry: Adaptive mesh refinement

Overture

Rapid geometry-to mesh capability using building datasets

Next-generation State-of-the-art Integrated Urban Dispersion Capability

- **Automatic mesh construction from building datasets.**
- **Geometrically complex buildings and cityscapes**
- **Applicable to diverse urban environments:** stadiums, arenas, subways, etc.

- **Adaptive mesh refinement capability**
- **Enhanced fidelity around important flow regions:** release source, building entrance, etc.
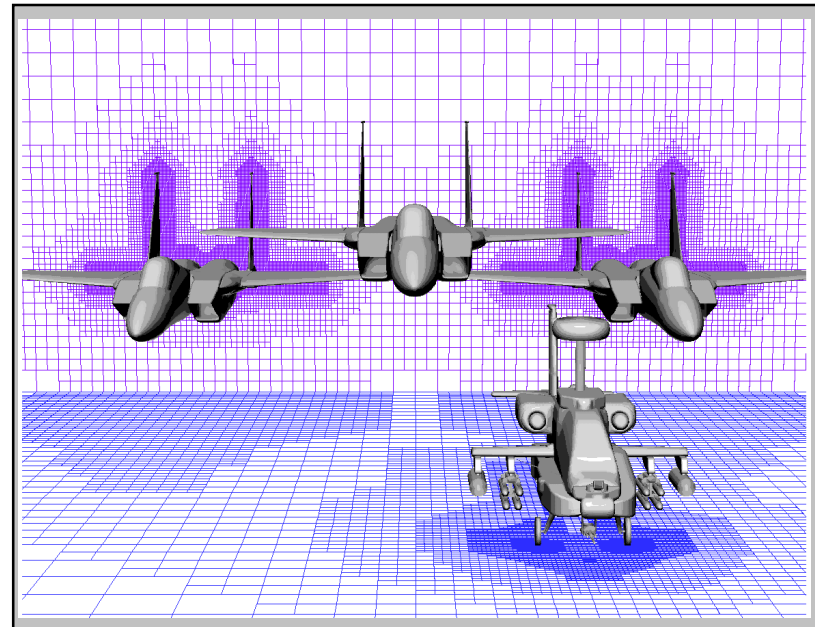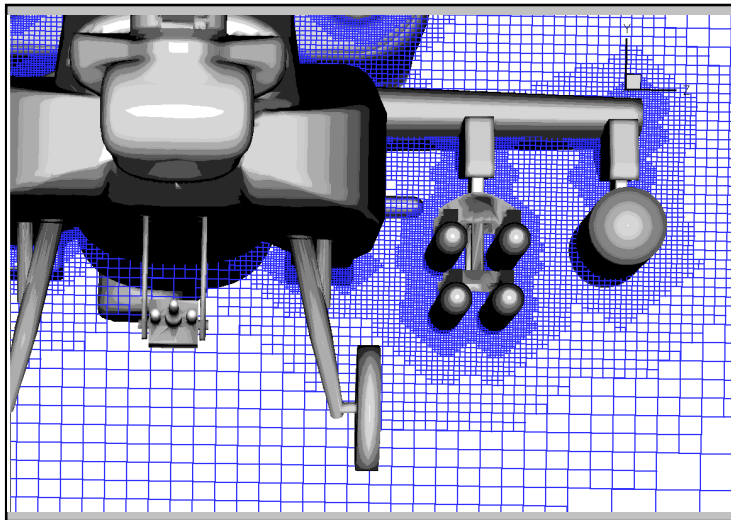- **Complex release scenarios:** moving sources, etc.

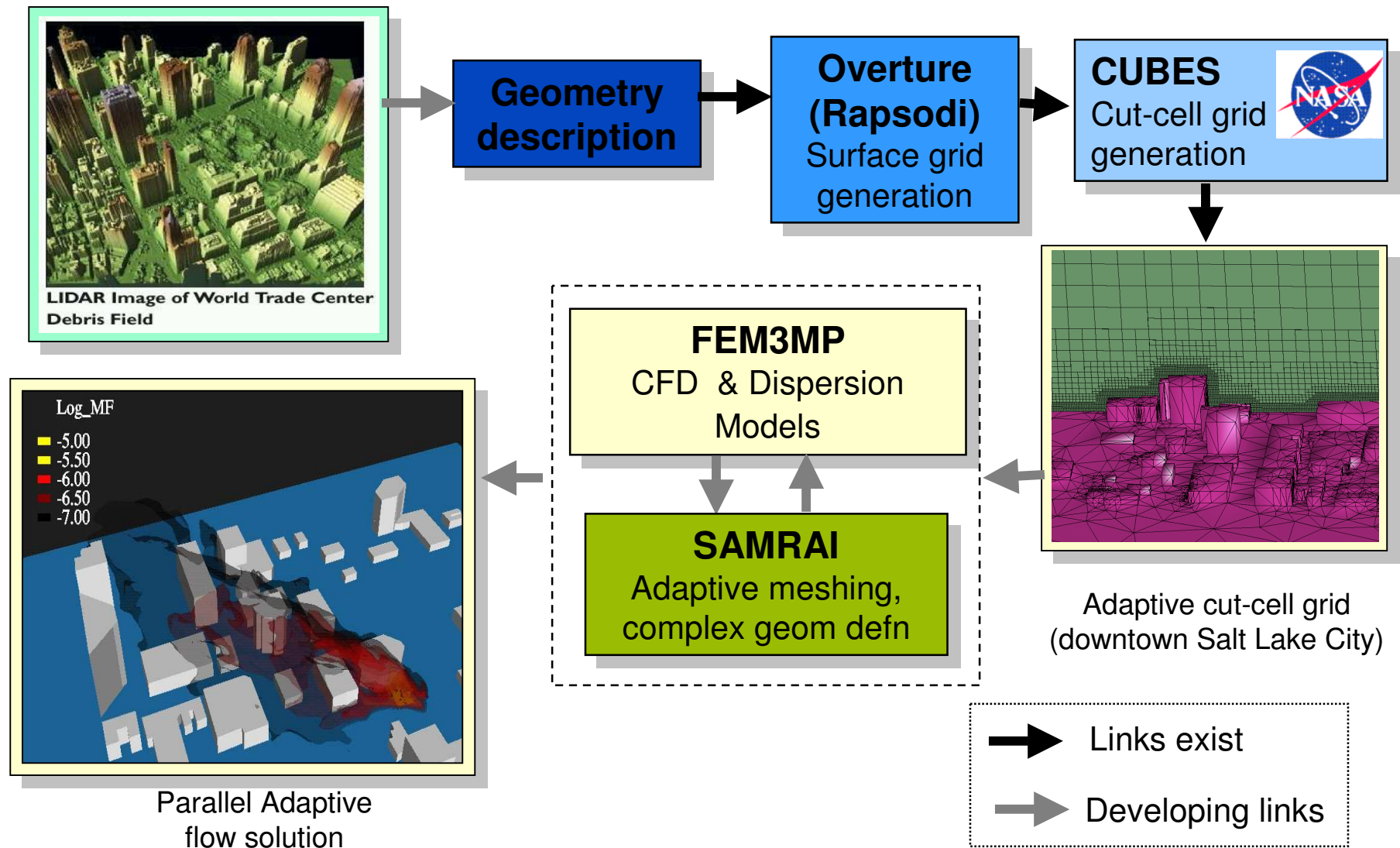# The CUBES software is used to build adaptive cut-cell volume grids

- **CUBES is a grid generator developed at NASA Ames for automated CFD analysis.**
  - Developed by Marsha Berger (NYU, Courant) and Mike Aftosmis (NASA Ames)
  - Readily handles complex geometries
  - Very fast

Example applications of CUBES – courtesy Berger, Aftosmis NASA Ames

An integrated set of tools will enable rapid geometry to solution capability

LIDAR Image of World Trade Center Debris Field

Geometry description → **Overture (Rapsodi)** Surface grid generation → **CUBES** Cut-cell grid generation

Adaptive cut-cell grid (downtown Salt Lake City)

FEM3MP CFD & Dispersion Models

SAMRAI Adaptive meshing, complex geom defn

Parallel Adaptive flow solution

Log_MF
- -5.00
- -5.50
- -6.00
- -6.50
- -7.00

→ Links exist

→ Developing links

Multidisciplinary Project Team

Technical team:

- **Kyle Chand (Overture, CASC)**   grid generation   25%

- **Brian Gunney (SAMRAI, CASC)**   AMR, numerical alg.   25%

- **Craig Kapfer (SAMRAI, CASC)**   AMR, software integ.   50%

- **Branko Kosovic (FEM3MP, ASD)**   atmospheric applic.   50%

- **Anders Petersson (Overture, CASC)**   grid generation   25%

- **Andy Wissink (SAMRAI, CASC)**   AMR, cut-cell grids   50%

Collaborator:

- **Marsha Berger (NYU, Courant)**   grid generation   (unfunded)

Customers and Funding

We are funded by the Threat Vulnerability Test and Assessment (TVTA) portfolio in the DHS S&T program.

National Release Advisory Center (NARAC) will be the primary customer

- NARAC is a part of the Emergency Preparedness and Response program in the DHS

- Infrastructure and critical facility protection, emergency response, vulnerability studies

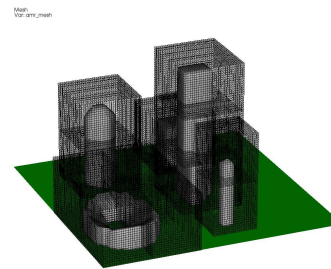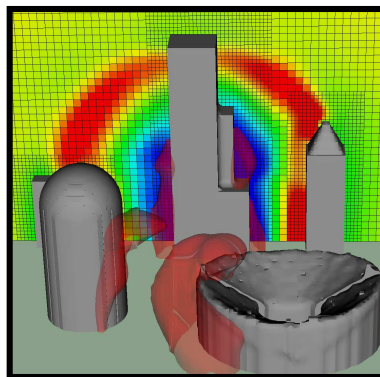# Demonstration calculations with prototype problems – 9/03

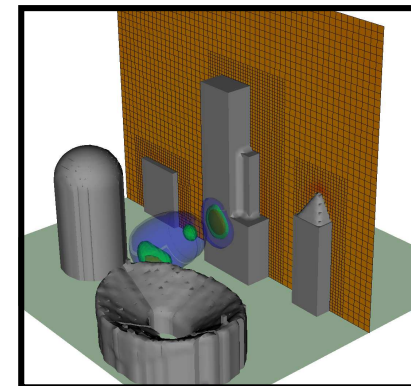- **Flow around stadium and sample cityscape with overset grids**
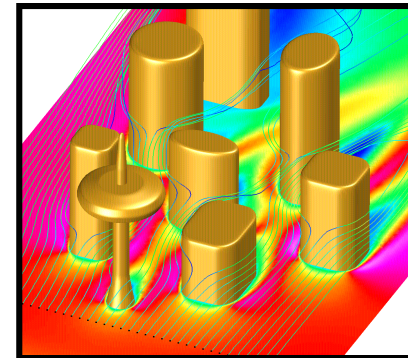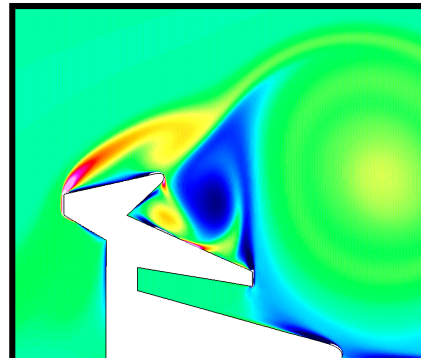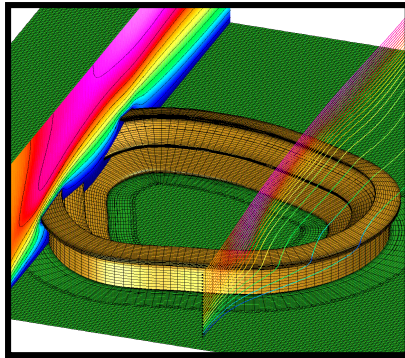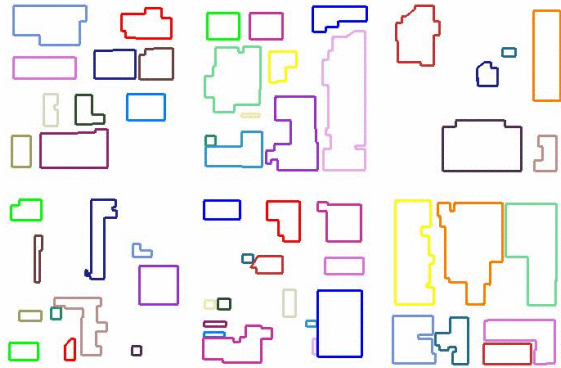

Henshaw 9/03

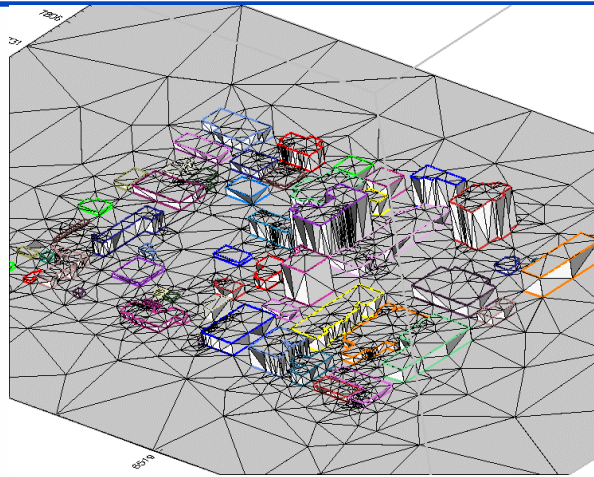- **Adaptive flow simulation over prototype cityscape with cut-cell grids**

Refined region around buildings

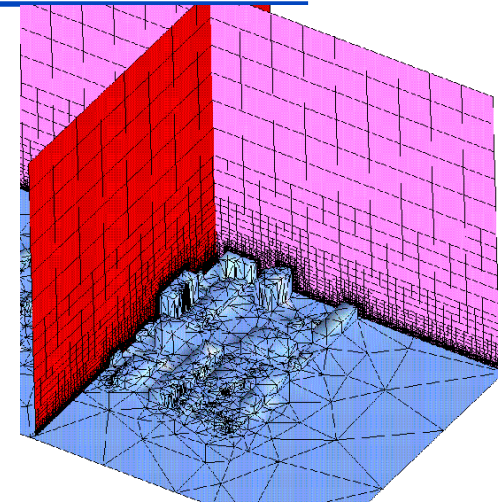# Automated cut-cell grid generation from building datasets – 1/04

Polygonal geometry
data (Salt Lake City)

Chand 1/04

Surface triangulation by
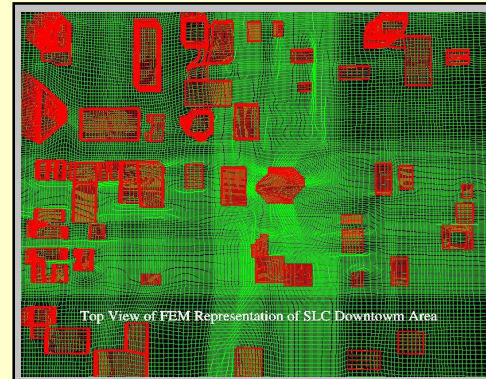metro

AMR volume mesh
by CUBES

- **"metro" reads building geometry data and generates surface triangulation and CUBES input**

- **GUI interface that allows user to interactively add/modify/delete buildings**

# Mesh generation with new tools is considerably faster than current tools

Downtown Salt Lake City

- **Structured conforming grid constructed with existing tools required about a <u>week</u>**

Top View of FEM Representation of SLC Downtown Area
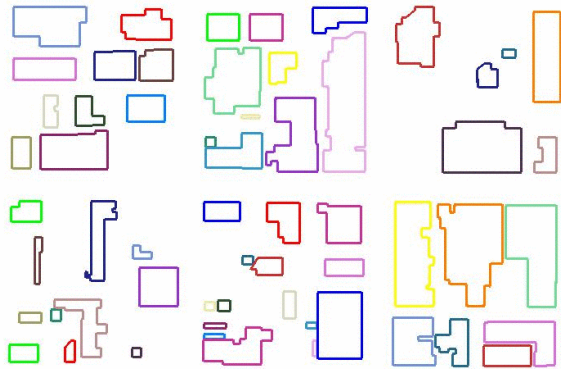
- **Adaptive cut-cell Cartesian grid generated with metro & CUBES required about <u>2 minutes</u>**
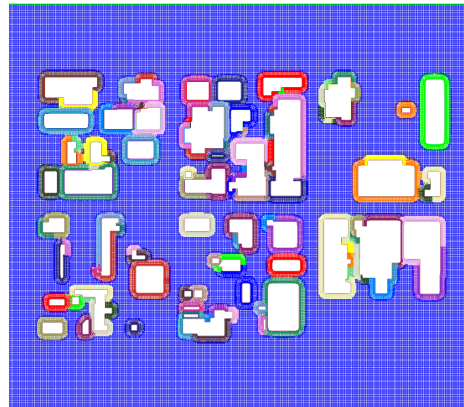
1.7M gridpoints, 6 levels refinement
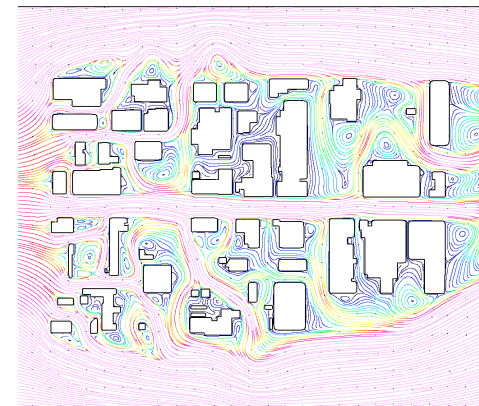Surface grid – 30 sec with "metro"
Volume grid – 45 sec with "CUBES"
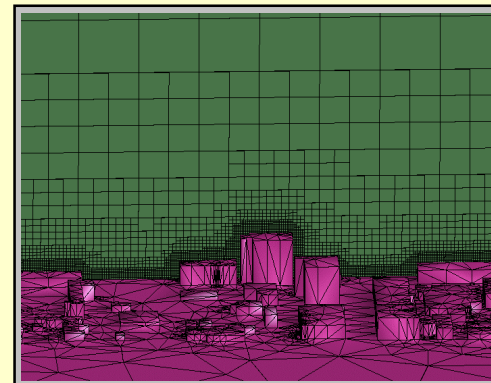
Automated overlapping grid construction from building geometry information

Polygonal geometry data (Salt Lake City)
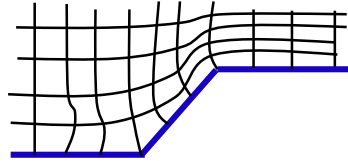
2D overlapping grid (ogen)

Henshaw 1/04

INS Solution (Overblown)

- **Body-fitted grids are automatically generated for each building**

- **Cartesian grid fills background and far-field**

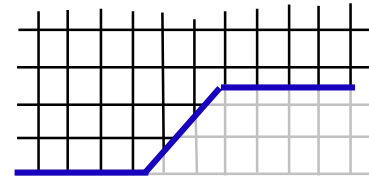- **Overlapping grid is automatically assembled**

Research issues still to be addressed in FY04

- **Finite element boundary representation on cut-cell grids – fictitious domain**

"conforming" mesh
(current)

"cut-cell" mesh
(new)

- **Adaptive algorithms for Q1Q0 and Q1Q1 element incompressible CFD solver**

- **Building geometry information that incorporates new features**
  — **Standard formats adopted by DHS?**
  — **Incorporating terrain**
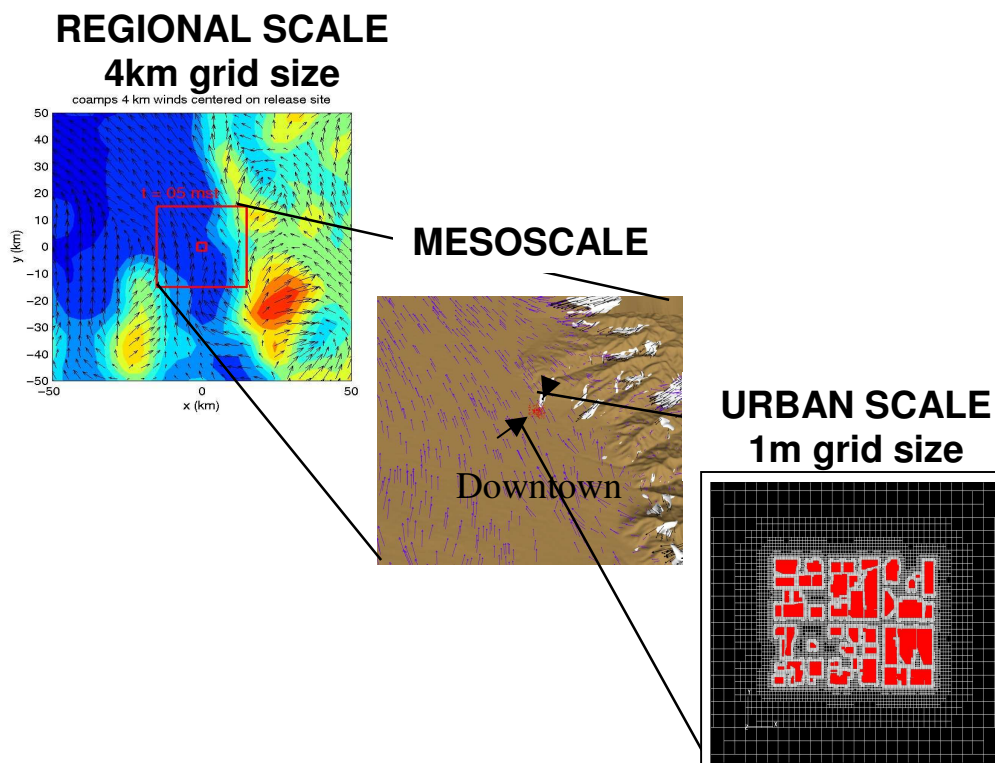
Wissink-14

Project Tasks and Timeline

- Demonstration calc with prototypes
- Develop geometry to mesh capability
- Develop CUBES/SAMRAI interfaces
- SAMRAI-FEM3MP integration
- Develop cut-cell FE algs
- Develop AMR capability
- Validation, refinement studies
- Fine-tune the performance for operational use

Started 6/03

Present 3/04

2003   2004   2005   2006

FY Timeline
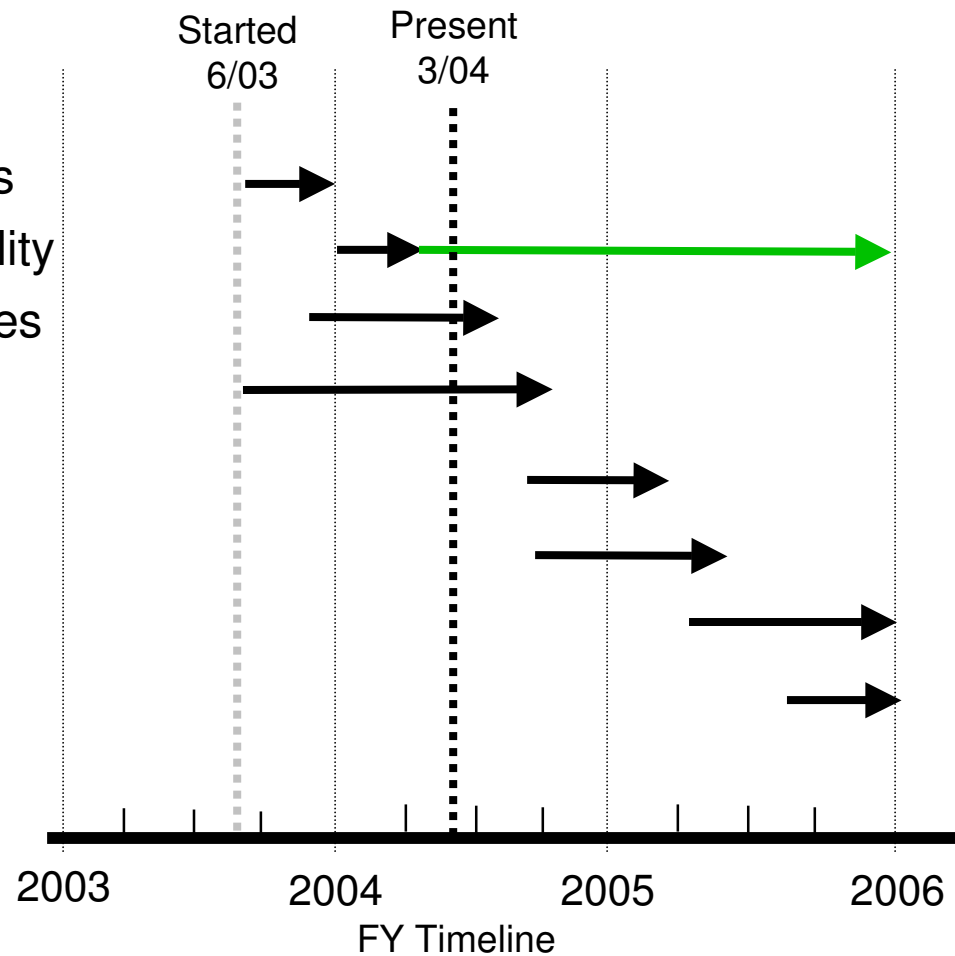
Potential Longer-term Research Challenges

- Coupling models with different scales

- Diverse urban environments – subways, arenas, etc.

URBAN DATA SOLUTIONS
Manhattan is three dimensionally mapped from 72nd Street to the Battery as well as Downtown Brooklyn

REGIONAL SCALE
4km grid size

coamps 4 km winds centered on release site

MESOSCALE

Downtown

URBAN SCALE
1m grid size

- Large-scale cityscapes (e.g. Manhattan)

- Performance on diverse parallel architectures

Conclusions

- We are pursuing an advanced urban dispersion modeling tool by combining expertise in meshing technologies from CASC and NASA with atmospheric model expertise in NARAC.

- The tool will be used for emergency response, scenario planning, and event reconstruction capability

- Our grid generation approach demonstrates it is possible to reduce meshing times from weeks to minutes.

- Anticipate fully adaptive tool to be available for operational use in NARAC by late 2005.

Acknowledgments